Study of soil erosion in the small loess agricultural catchment in the light of ^{137}Cs measurements

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1. Abstract

In this work ^{137}Cs tracer was used to study soil erosion on the agricultural field and to measure soil redistribution on the small agricultural catchment with loess cover. Soil samples from the study catchment were taken and the ^{137}Cs activity were measured by the gamma spectroscopy. The obtained results of ^{137}Cs inventory suggest that soil movement for the study area is considerable. The ^{137}Cs inventories were 10-82% lower on the slopes than plateau. For the sampling point at bottom of the valley the ^{137}Cs inventories wary from 1220 Bq/m^2 to 10360Bq/m^2. The calculated mean value of soil erosion for the study catchment is about 24 tons per hectare for a year and about 60 % is redeposit in the study catchment at the accumulation base. The maximum value of soil erosion for study catchment is about 11 mm per year for a sampling point located on the 12° slope.

2. Introduction

Soil degradation by water and wind erosion is a serous problem in most countries. Furthermore, loessial soils are very susceptible to water erosion processes. Even small inclination of few degrees may result in medium to large water erosion of loessial soil. Additionally, an inappropriate soil tillage intensifies the soil erosion. To choose an appropriate method of soil conservation the rate of soil erosion should be known. There are many method to estimate soil erosion but traditional method have many limitations. On this background the method of soil erosion measurement based on the ^{137}Cs method overcomes many limitations of the traditional methods to measure soil erosion as well as the empirical models such as USLE or RUSLE. The detailed discussion of the advantages and limitations of the ^{137}Cs method has been presented by Ritchie and McHenry (1990). This isotope has been present in the environment since the beginning of nuclear weapon testing and nowadays ^{137}Cs is a part of many ecosystems. ^{137}Cs seems a valuable tracer to study soil erosion and sedimentation because after deposition ^{137}Cs on the land surface is rapidly and strongly adsorbed by soil particles (Schulz et al., 1960) and thus its redeposition in the soil environment is together with the soil particles. In few words, this method is based on the comparison of the ^{137}Cs inventories in sampling points with a reference inventory. The reference inventory presents the local input fallout of ^{137}Cs. This means that for a reference site neither erosion nor deposition of soil occurred. The estimation of the local input fallout of ^{137}Cs is problematic especially in regions where undisturbed sites are unusual. The simply comparison between ^{137}Cs inventory at sampling point and reference ^{137}Cs inventory allows recognising erosion and deposition areas; to obtain quantitative estimation of soil erosion, however, one of the models should be used (Walling *et al*., 1990; Walling *et al*, 1999). Those relationships allow converting ^{137}Cs data into erosion rate data.

This paper describes the measurement of ^{137}Cs activity in cultivated loessial soil. We measured the activities of ^{137}Cs in soil samples in a small agricultural catchment. The study area was contaminated by ^{137}Cs from Chernobyl accident. Cesium-137 method was used as a tool to investigate soil erosion and accumulation for small agricultural catchment. The value of the erosion rate was obtained by applying the mass balance models as well as the proportional model. The aim of this study is to evaluate the soil erosion and accumulation rates for the agricultural field located on the loess slope as well as to evaluate the structure of soil redistribution for the study catchment.

3. Site and Methods

The study area selected for the investigation is a small agricultural valley located on the Proboszczowicki tableland near (Ujazd village, South Poland; 50°24′ N, 18°24′ E). The average inclination for the slopes of the study area is 10º and the study area is about 38 ha. The average annual rainfall for study area is 675 mm. Generally, the highest intensity of precipitation is in July. The highest daily rainfall was recorded in July 1997 – 257,8 mm. The study area has been cultivated since at least the end of the Second World War. The study area was contaminated by the cesium from Chernobyl accident. From the study area five valley profiles were taken from this area. Additionally were taken soil cores from the base of the catchment (figure 1). Moreover to obtain the reference value of ^{137}Cs inventory were taken 12 soil cores from the are where neither soil erosion or deposition occurs. The scheme of the sampling is presented in figure 1. Soil samples were collected in October 2003. The soil samples were taken by means of the 80 mm diameter borer. Three soil cores were taken at each location and the composite sample for a given depth was formed. Usually soil cores were taken to the depth 80-90 cm on the slope and at the top, but at the slope base soil cores were taken down to a depth of 150 cm. Each core was sectioned into 10 cm sections. Soil samples were dried in the dryer until their mass was constant and sieved to remove stones and visible parts of plant roots. A prepared sample was then placed in the Marinelli beaker. The average mass of measured soil samples was 500 g. The activity of ^{137}Cs in samples was measured by high-resolution gamma spectrometry with HPGe detector manufactured by CANBERRA. The resolution was 1.8 keV at 1,33 MeV energy and relative efficiency of 35%. The counting time was usually 80 ksec. Finally, activities of ^{137}Cs in soil samples were expressed in Bq/kg of dry mass of soil on the date of collection, corrected for the radioactive decay.

4. Results

The results of the ^{137}Cs inventories in soil in the example of the valley profile at studied locations are presented in the Figures 2. Generally the spatial variations in the ^{137}Cs inventories in soil could be used to identify the areas of erosion and deposition. It is quite visible that for almost all sampling points located on the slopes the ^{137}Cs inventory is lower than the reference inventory. The lower values of ^{137}Cs inventories were found on the slopes (10-12^{o} slope inclination). Moreover for some sampling points located at the bottom of the valley the ^{137}Cs inventory were found to be considerable lower than the ^{137}Cs reference inventory. It might seem surprising but those group of sampling point ore not only the deposition area. This area is rather a transit place. The highest ^{137}Cs inventory was found at the valley bottom for valley profile No 3. For this sampling point the ^{137}Cs inventory is 10.36±0.84 kBq/m^2. A little smaller value of the ^{137}Cs inventory is 10.06±0.86 kBq/m^2. By this way the deposition of soil at this site is confirmed and in addition wide range of value of the ^{137}Cs inventory shows that the rate of this process is rather high. The values of the ^{137}Cs inventories at the top of the slopes are no significant statistical different than the reference inventory of ^{137}Cs. All results of the ^{137}Cs inventories for the study catchment grouped at three groups according the morphology (top, middle and bottom of the slope) are presented on the figure 3

The simple comparison between reference ^{137}Cs inventory and measured ^{137}Cs inventory allows recognizing erosion and deposition areas; however, to obtain quantitative estimates of soil erosion one of the models should be used (Walling *et al*, 1999). Soil erosion and deposition rates for the study area were calculated by using the proportional model (Walling *et al*., 1990) and by using two of the mass balance models: improved and simplified (Zhang et al., 1999; Walling et al.,1999). Although the simplified MBM is very easy to use, the main assumption of this approach that the total ^{137}Cs fallout input occurred in 1963 seems to be an oversimplification especially for the study area where strong additional deposition connected with the Chernobyl accident occurred. The improved MBM model considers the annual fallout ^{137}Cs inputs as well as the losses of ^{137}Cs from the soil due to erosion before mixing with soil by ploughing.
The values for the additional parameters required by the models were estimated using information about local soil and rainfall condition. The results of estimation of soil redistribution rates derived from the ^{137}Cs measurements are summarized on Figure 5 whereas an example of the variations of the soil erosion on the valley profile are presented on Figure 4. The results presented on Figure 4 indicate the results of soil erosion are different for different models. The visible difference between results of soil erosion obtained by different model are mainly due to its limitations e.g. the proportional model does not consider the fate of the freshly deposited fallout before its incorporation into the plough layer by cultivation. The mass balance models generally has not this limitation. Only the simplified mass balance model has this inconvenience. This model provided the results of the soil erosion quite different from the improved mass balance model. It should be mentioned that even proportional model provided results of soil erosion in better agreement to mass balance models than simplified mass balance model. That is because the assumption of simplified mass balance model is that the total ^{137}Cs fallout occurred in 1963. It is oversimplification but there is an additional problem for study area. The study area is strongly contaminated by ^{137}Cs from Chernobyl accident. The calculated mean value of soil erosion for the study catchment is about 24 tons and about 60 % is redeposit in the study catchment at the accumulation base. The maximum value of soil erosion for study catchment is about 11 mm per year for a sampling point located on the 12° slope.

5. Conclusion

The study of ^{137}Cs measurement of soil in Ujazd area has shown the potential of this method to assess the soil erosion and deposition. The mean estimated erosion for the slopes for study area is about 24 t/ha·yr. The highest value of soil erosion was found for the sampling point located on the middle slope with inclination about 12° and also for the valley bottom for valley profile 2. This reflect the high dynamic of soil movement at bottom of valley. The results obtained by simplified MBM are higher than results obtained by other model. The results of soil erosion obtained by the proportional model are quite similar to the improved MBM. Generally the improved mass balance models provides more realistic results of soil erosion than other models, but the simplified mass balance model provided probably the most inappropriate results of soil erosion. The obtained results show that this technique could be used for area where contamination by the cesium from Chernobyl accident was high but with the extreme caution. For this kind of areas only mass balance model, where the annual fallout ^{137}Cs input is consider, provided reliable results of soil erosion estimation. The mean denudation for the whole study catchment is 2.0 mm/year and about 40 % of the eroded soil is removed outside the study catchment.

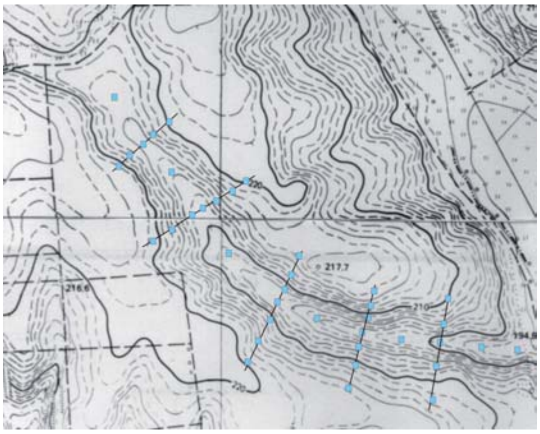

Figure 1 Study area and sampling scheme

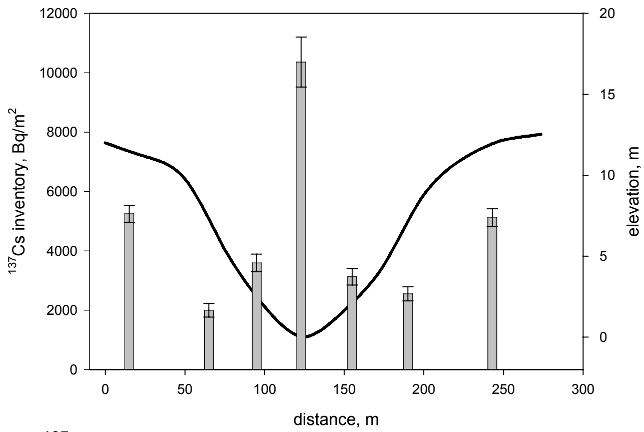

Figure 2 The inventories of ^{137}Cs distribution across the valley (an example) with the sketch of the valley.

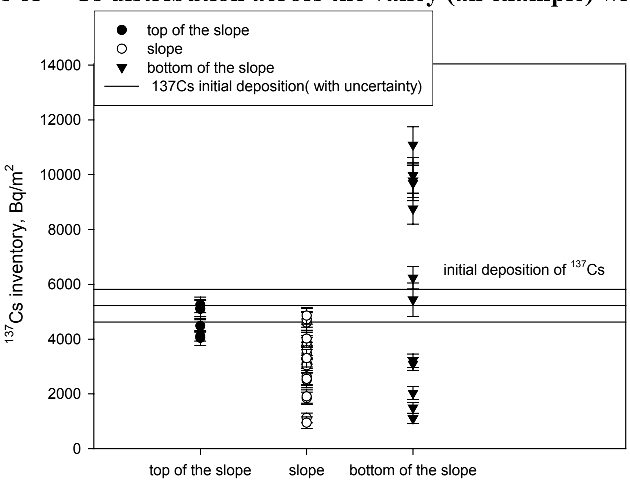

Figure 3 All results of ^{137}Cs inventory obtained for the study area. The results are grouped into three categories due to local morphology. The reference value of ^{137}Cs inventory is also marked (with uncertainty)

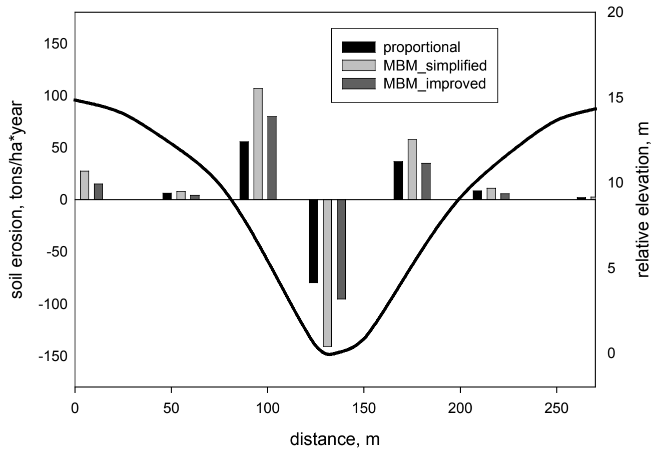

Figure 4 The results of calculation of the soil erosion and deposition by three models. The sketch of the valley is also marked

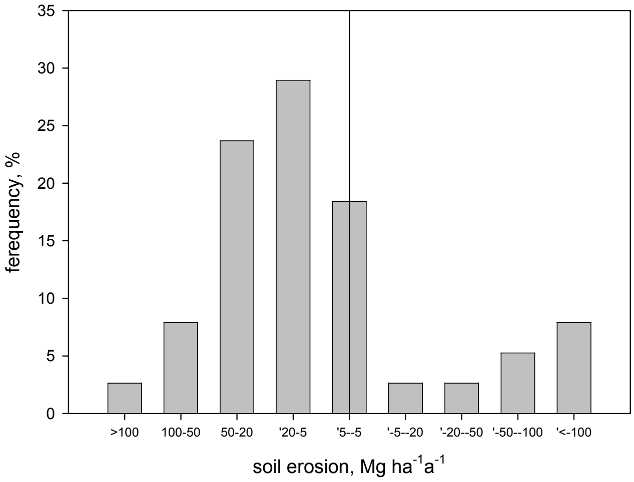

Figure 5 The distribution of the calculated soil erosion rate and soil deposition value for the study valley.

6. References

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